



RESEARCH DEPARTMENT



REPORT

**Pulse code modulation of video signals:
subjective tests on acceptable
limits for timing jitter in the
decoded analogue samples.**

No. **1971/42**

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SUBJECTIVE TESTS ON ACCEPTABLE LIMITS FOR
TIMING JITTER IN THE DECODED ANALOGUE SAMPLES**

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PULSE CODE MODULATION OF VIDEO SIGNALS: SUBJECTIVE TESTS ON ACCEPTABLE LIMITS FOR TIMING JITTER IN THE DECODED ANALOGUE SAMPLES

Summary

Tests have been performed to investigate the subjective effect, on a television display, of timing jitter in the samples of a 625-line video signal obtained from a p.c.m. digital-to-analogue converter. The results of these tests have been used to obtain limits for the amount of both random and sinusoidal forms of jitter which can be tolerated in a broadcast-quality television system.

1. Introduction

In most pulse code modulation systems, it is important that the pulses should arrive at regular intervals at the digital-to-analogue converter. Assuming that all timing information is derived from the p.c.m. pulse train, any timing jitter in these pulses causes pulse-position modulation of the samples forming the decoded analogue signals, thus introducing unwanted components. A very large amount of timing jitter will also cause errors in the p.c.m. decoding process, i.e. 0's may be decoded as 1's and vice versa, but this extreme condition will not be considered in the present report.

In practice, a certain amount of jitter is introduced by regenerative repeaters used in long transmission links. In such repeaters, the pulses are re-timed using clock pulses derived from the p.c.m. pulse trains; jitter is then introduced by noise and because the timing of these derived clock pulses is affected by the pattern density, i.e. the relative proportions of ones and zeros, in the pulse train.

If necessary, the jitter in a p.c.m. pulse train may be reduced prior to digital-to-analogue conversion by a re-timing process which is more efficient than that used in the repeaters.^{1,2} The reduction in the amount of jitter resulting from this final re-timing process is obtained at the cost of instrumental complication and it is therefore desirable to know the amount of jitter which can be tolerated in the decoded signal. For this reason, the subjective tests described in this report were performed to examine the effect, on a television display, of varying amounts of jitter in the analogue samples obtained from a p.c.m. system handling video signals.

The characteristics of the unwanted noise introduced by jitter depend to a certain extent on the method of determining the duration of the analogue samples obtained from the digital-to-analogue converter. Fig. 1 illustrates the effect of two different methods with a series of analogue samples whose relative magnitude and starting times are given by S_1, S_2 etc in Fig. 1(a); in this figure S_3

and S_6 are incorrectly timed each being delayed by time τ . Fig. 1(b) illustrates the case in which the magnitude of each sample is held constant until the following sample is decoded; this will be referred to as the boxcar method and was used in the equipment described in reference 3. Fig. 1(d) illustrates the alternative case in which all the samples have the same duration 't' which is less than the sampling period; this will be referred to as the constant-duration method and was used in the equipment described in reference 4. Figs. 1(c) and 1(e) corresponding to Figs. 1(b) and 1(d) respectively, show the extent of the errors in the decoded analogue signal produced by the mistiming of samples S_3 and S_6 .

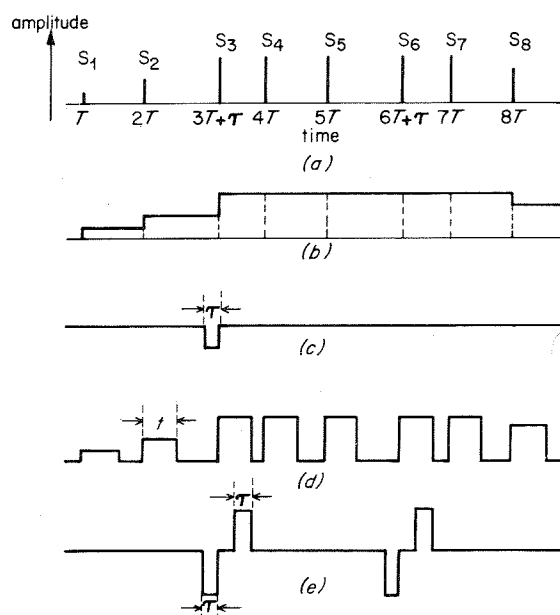


Fig. 1 - Effect of mistimings of analogue samples

- (a) Relative amplitudes and time of start of samples
- (b) Waveform obtained with sample held constant until arrival of following sample - boxcar method
- (c) Error in waveform (b) caused by mistiming of S_3 and S_6
- (d) Waveform obtained with samples of constant duration
- (e) Error in waveform (d) caused by mistiming of S_3 and S_6

It will be seen that the boxcar method has the advantage that the mistiming of a sample such as S_6 , which is preceded by another of the same magnitude, produces no overall error (see Fig. 1(c)) whereas, in the constant duration method errors are produced by the mistiming of both S_3 and S_6 (see Fig. 1(e)). On the other hand, when there is a large difference between the magnitudes of a mistimed sample and the preceding sample, the errors resulting from the constant duration method may have such a spectrum as to be less visible than those produced by the boxcar method. The spectrum of any error produced by the boxcar method has maximum amplitude at d.c. whereas the spectrum of an error from the constant duration method has zero amplitude at d.c. and a maximum amplitude at about $1/2t$, which is above the cut-off frequency of the low-pass filter following the decoder. It is thus very difficult to predict which is the better method for the majority of pictures. For the subjective tests described in this report, the only available type of digital-to-analogue converter used the boxcar method, and all further discussion relates to this type of equipment.

Although a bandwidth of about 100 MHz would be required to transmit the type of p.c.m. video signal used for the tests described in this report, only jitter frequencies up to 6 MHz were examined since the pulse re-timing circuits used in normal p.c.m. decoders can easily remove components at higher frequencies.

2. Effect of jitter on video signals

Assuming that its magnitude is insufficient to cause digital errors, the most noticeable effect of any jitter in a video signal is that it causes unwanted variations in the hue of coloured areas of a picture. With random forms of jitter, these variations look similar to those obtained by additional noise in the chrominance channel; on the other hand, sinusoidal jitter produces regular patterns similar to those caused by co-channel interference. The magnitude of the unwanted components in the colour difference signals is directly proportional to the amplitude of the colour subcarrier and therefore the resulting picture degradation is most noticeable with 100% saturated colours.

With monochrome signals it was found that, with increasing magnitude of jitter, digital errors normally appeared before any other impairment was observed.

The effect of jitter on coloured areas of a picture depends to a certain extent on the characteristics of the phased-locked loop used in the colour decoder to lock the subcarrier reference oscillator to the subcarrier burst in the video signal. Typical phase-locked loops used for this purpose will follow phase modulation of the burst if the modulating frequency is below 100 Hz; hence only jitter components at frequencies above 100 Hz will cause variations in the hue on the television display.

3. Subjective tests

3.1 Equipment

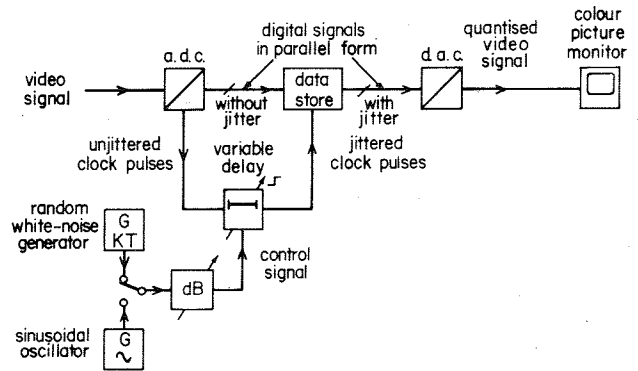


Fig. 2 - Block diagram of test equipment

A block diagram of the equipment is shown in Fig. 2. The video analogue-to-digital converter (a.d.c.) and digital-to-analogue converter (d.a.c.) used for the tests are described in reference 3. In the a.d.c., the video signal was sampled at a rate of approximately 13.3 MHz and each sample was coded into a 8-digit binary number; these 8 digits were then fed to the decoder in parallel form along separate wires.

The jitter on the analogue samples was produced by re-timing the digital signals in a store controlled by jittered clock pulses. This store consisted of one D-type flip-flop in each of the 8 digital signal paths. All eight flip-flops were triggered by the same clock pulse train so that all the digits corresponding to a given sample were jittered by the same amount.

To produce jitter on the clock pulses, a train of regularly spaced pulses from the coder were passed through a voltage-controlled variable-delay unit. The mean delay of this unit was equal to twice the period between clock pulses, i.e. 150 ns, and the range over which the delay was linearly related to the control voltage was about ± 5 ns. A circuit diagram of this delay unit is shown in Fig. 3. It can be seen that the clock pulses pass through a series of gates connected by RC integrating circuits. Delay variations were obtained by altering the voltage across variable-capacitance diodes, thus changing the time constants of the coupling circuits.

The peak-to-peak variations in the delay produced by constant amplitude sinusoidal control signals of different frequencies were equal within ± 1 dB from 0 to 4 MHz and within ± 2 dB up to 6 MHz.

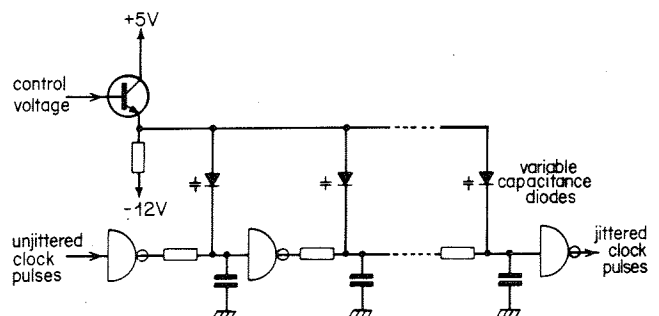


Fig. 3 - Circuit diagram of voltage-controlled variable delay

Both random Gaussian and sinusoidal forms of jitter were used in the tests. The control voltage for the random jitter was obtained from a white noise generator, the output of which passed through a low-pass filter having a cut-off frequency of either 20 KHz, 600 KHz or 6 MHz; these frequencies were selected to cover the possible range of jitter bandwidths obtained from clock pulse regenerators having acceptable performance with respect to such factors as lock-up time. The sinusoidal control voltage was obtained from a crystal-controlled frequency synthesiser giving a very stable frequency so that the resulting interference patterns stayed constant throughout the tests. Six different frequencies were used in the tests on sinusoidal jitter; these frequencies were relatively evenly spaced over the video frequency band and were selected to give patterning effects of high visibility.

The video signal used in all the tests was provided by a colour bar generator set to 100% saturation and operating on the 625-line PAL television standard. The reasons for using 100% colour bars were firstly, because, as explained in section 2, 100% saturated colours provide the most critical type of picture information and secondly, because the effects of jitter are most obvious in large plain areas.

The video signals from the d.a.c. were displayed on a high-quality 19" monitor having a peak brightness of 55 candelas/metre² (16 ft-L); with zero beam current, the brightness of the monitor resulting from ambient illumination was 0.1 candelas/metre² (0.03 ft-L).

3.2 Test procedure

Each test condition was shown to six observers seated at a distance of six times picture height from the picture monitor. The observers were all engineers or technicians having previous experience of assessing picture quality.

The picture impairment introduced by the jitter was graded using the EBU impairment scale given in Table 1.

TABLE 1
EBU impairment scale

Grade	Degree of impairment
1	Imperceptible
2	Just perceptible
3	Definitely perceptible but not disturbing
4	Somewhat objectionable
5	Definitely objectionable
6	Unusable

This scale was used in different ways in two separate series of tests which are discussed below.

3.2.1 Method I

In this method, each observer was asked to adjust the variable attenuator in the jitter signal path (see Fig. 2) until the picture impairment was judged to be grade 1.5 on the scale given above. All the different forms of jitter mentioned in section 3.1 were assessed.

Each observer completed the entire series of tests without any other observers being present.

3.2.2 Method II

When the first series of tests had been completed, it was decided that it would be useful to obtain information on the manner in which the impairment increased for amplitudes of jitter higher than that corresponding to grade 1.5. For this reason, a second series of tests were carried out in which a group of six observers were asked to grade the impairment caused by different amounts of random jitter. The amount of jitter was varied from a value causing negligible impairment up to the maximum obtainable from the equipment; the various conditions were presented in an arbitrary order, each being given twice.

4. Results

A summary of the results for test methods I and II is given in Table 2 and Fig. 4 respectively.

TABLE 2
Amplitude of Jitter for Impairment Grade 1.5

Type of jitter	Frequency or Bandwidth	r.m.s. amplitude of jitter	Standard Deviation
Sinusoidal	553 Hz	0.06 ns	3.5 dB
Sinusoidal	6.00 KHz	0.19 ns	2.0 dB
Sinusoidal	66.7 KHz	0.48 ns	2.6 dB
Sinusoidal	60.1 KHz	0.19 ns	3.1 dB
Sinusoidal	3.00 MHz	0.27 ns	3.8 dB
Random	20 KHz	0.27 ns	1.8 dB
Random	600 KHz	0.48 ns	3.1 dB
Random	6 MHz	0.42 ns	4.1 dB

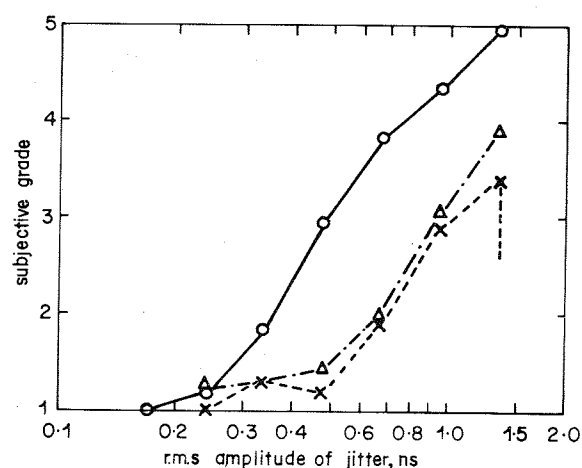


Fig. 4 - Impairment caused by white Gaussian jitter on display of 100% colour bars

—○— Maximum jitter frequency = 20 kHz
 - -△- - Maximum jitter frequency = 600 kHz
 - -×- - Maximum jitter frequency = 6 MHz

It will be seen that both test methods gave very similar figures for the amplitude of random jitter corresponding to grade 1.5 impairment, i.e. 0.5 ns r.m.s. for bandwidths of 600 KHz and 6 MHz or 0.3 ns for a bandwidth of 20 KHz.

Table 2 shows that, for a given r.m.s. amplitude, sinusoidal jitter at critical frequencies is more noticeable than random jitter. The most critical jitter frequencies were those that produced moving patterns which caused a low-frequency flickering effect on the monitor.

All the results mentioned above were obtained using 100% colour bars as the video signal. Subsidiary tests were also carried out using a video signal from a colour slide scanner in which the saturation did not exceed about 20%. With this signal, it was found that the impairment only reached about grade 1.5 with random jitter having the maximum amplitude available from the equipment, i.e. 1.3 ns r.m.s. This result was to be expected from the tests using colour bars since the amplitude of the unwanted components resulting from distortion of the colour sub-carrier is proportional to the saturation of the subcarrier; thus with 20% saturation, the amplitude of the jitter corresponding to a given impairment would be 5 times that required for 100% saturation.

5. Conclusions

The effect of timing jitter in the decoded samples from a video p.c.m. system has been investigated by subjective tests.

For broadcast quality pictures, the amplitude of random Gaussian jitter with a flat frequency spectrum up to 600 kHz or 6 MHz should not be greater than 0.5 ns r.m.s.; if the spectrum is limited to be range 0 – 20 kHz, the amplitude should not be greater than 0.3 ns r.m.s. For sinusoidal jitter the acceptable limits depend a great deal on its repetition frequency; for the most critical frequencies, the amplitude should not be greater than about 0.1 ns r.m.s.

6. References

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